Finite element model: “Hydro-FE”

1. Fluid-Structure Interaction (Hydro), finite element model (FE) with “Morison Equation.”
2. Normal and tangential drag characteristics.
3. Geometric and material properties of mooring system and kelp.
4. Detailed wave and velocity profile input
5. Dynamic simulations, calculate stresses get tensions

Kelp model validation at 1 and 122 meter scales

{Developed by Drach, Dewhurst, Fredriksson, Tsukrov, DeCew, Knysh etc.)

Hydro-FE: Hydrodynamic Forces

"Morison's Equation" (Morison et al., 1950)

$$\boldsymbol{f} = \frac{1}{2}\rho D_{\mathbf{n}} C_n |\boldsymbol{U}_{\boldsymbol{Rn}}| \boldsymbol{U}_{\boldsymbol{Rn}}^{\beta_{\mathrm{n}}-1} + \frac{1}{2}\rho D_{\boldsymbol{t}} C_t |\boldsymbol{U}_{\boldsymbol{R}\mathbf{t}}| \boldsymbol{U}_{\boldsymbol{R}\mathbf{t}}^{\beta_{\mathrm{t}}-1} + \rho A \dot{\boldsymbol{U}}_{\boldsymbol{Rn}} + \rho A C_a \dot{\boldsymbol{U}}_{\boldsymbol{Rn}}$$

$\boldsymbol{f}$: force per element length

$D_{\mathbf{n}} C_n$: Normal drag area per element length (from tank tests)

$|\boldsymbol{U}_{\boldsymbol{Rn}}| \boldsymbol{U}_{\boldsymbol{Rn}}^{\beta_{\mathrm{n}}-1}$: Normal relative velocity, includes wave/currents/interaction. Option of a nonquadratic dependence

$D_{\boldsymbol{t}} C_t$: Tangential drag area per element length (from tank tests)

$|\boldsymbol{U}_{\boldsymbol{R}\mathbf{t}}| \boldsymbol{U}_{\boldsymbol{R}\mathbf{t}}^{\beta_{\mathrm{t}}-1}$: Tangential relative velocity, includes wave/currents/interaction. Option for a nonquadratic dependence

$\rho A \dot{\boldsymbol{U}}_{\boldsymbol{n}}$: Inertia force with relative accelerations

$\rho A C_a \dot{\boldsymbol{U}}_{\boldsymbol{Rn}}$: Added mass force with relative accelerations

C_a =1 , could discuss this more…

Contribution from Drs. T. Dewhurst and A. Drach

Results: Model Validation with Tank Tests (1-m)

Geometric and material properties of model aggregate

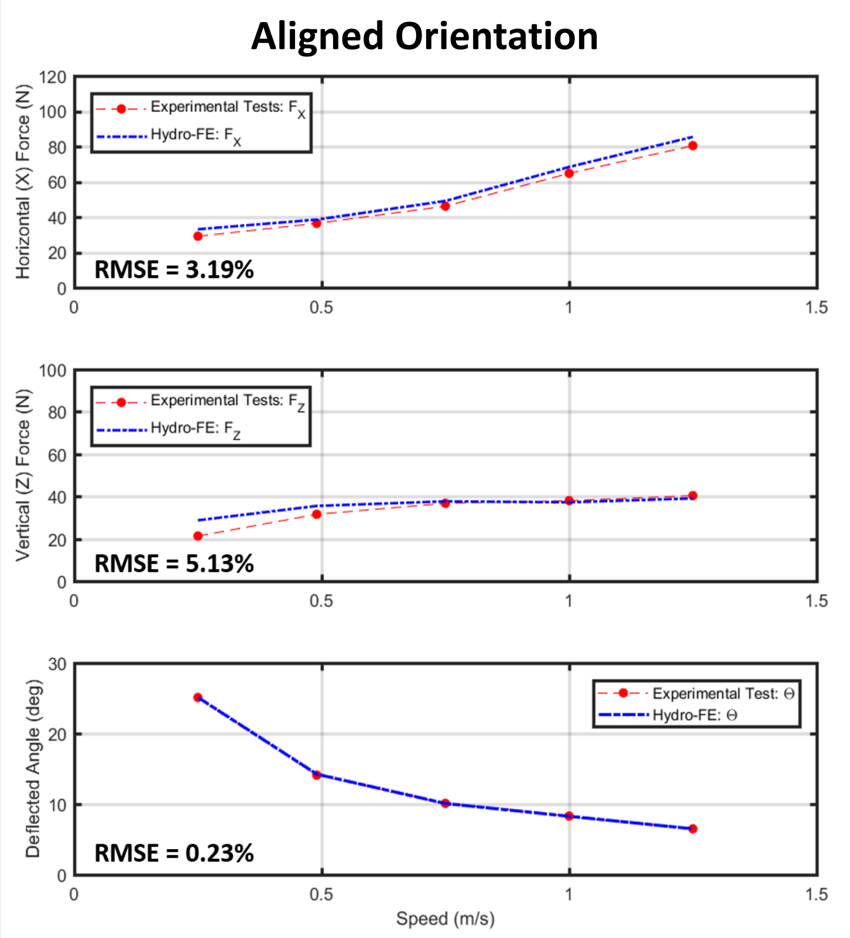
Reproduce force block measurements with model

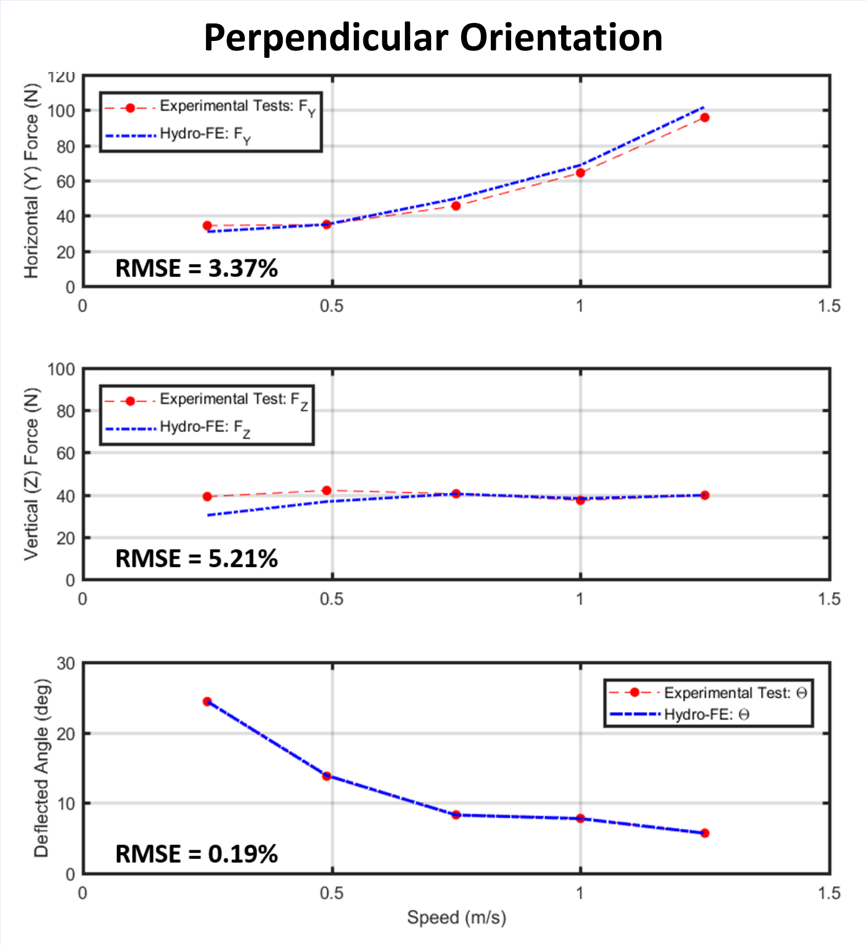
Kelp length: 3 m
Mass/grow length: 16 kg/m
Mass density: 1379 kg/m^3

Cross section area: 3.9 (10^{-3}) m^2
Volume diameter: 0.07 m
Drag dimension: 1 m

Young's modulus: 367 MPa
Second area moment: 1.058 (10^{-11}) m^4
Poisson ratio: 0.4

No velocity reduction at 1-m scale





Results: Model Validation with Field data (122-m)

1-Dimensional Momentum Balance for Current Reduction

Geometric and material properties of kelp aggregate

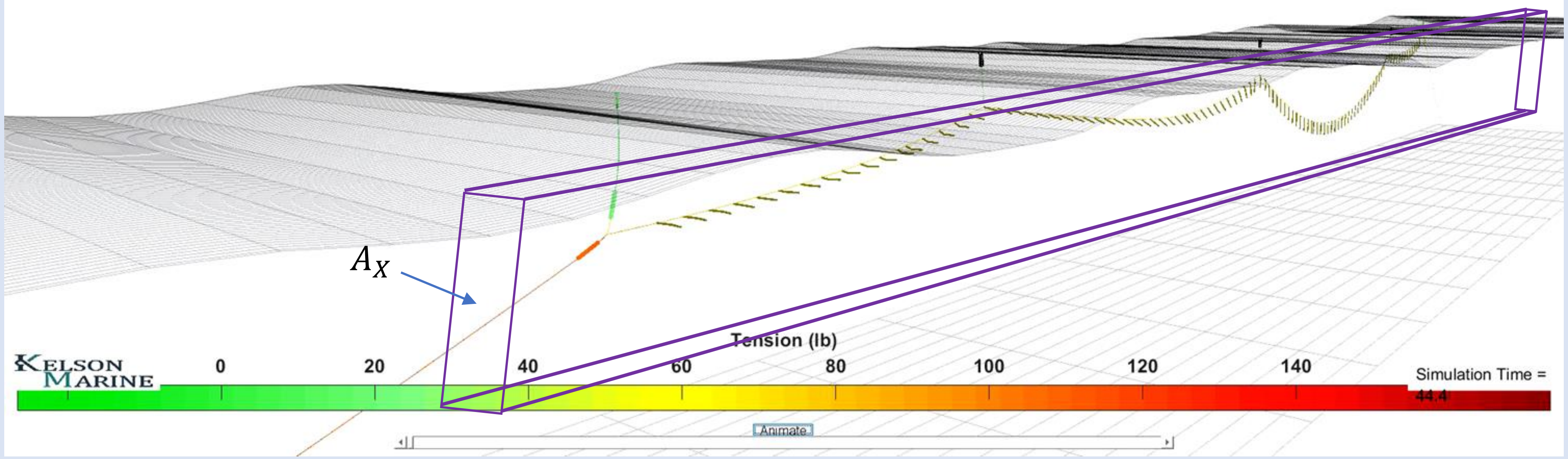
Kelp length: 1 m
Mass/grow length: 5.37 kg/m
Mass density: 1074 kg/m^3

Cross section area: 5.0 (10^{-3}) m^2
Volume diameter: 0.08 m
Drag dimension: 1 m

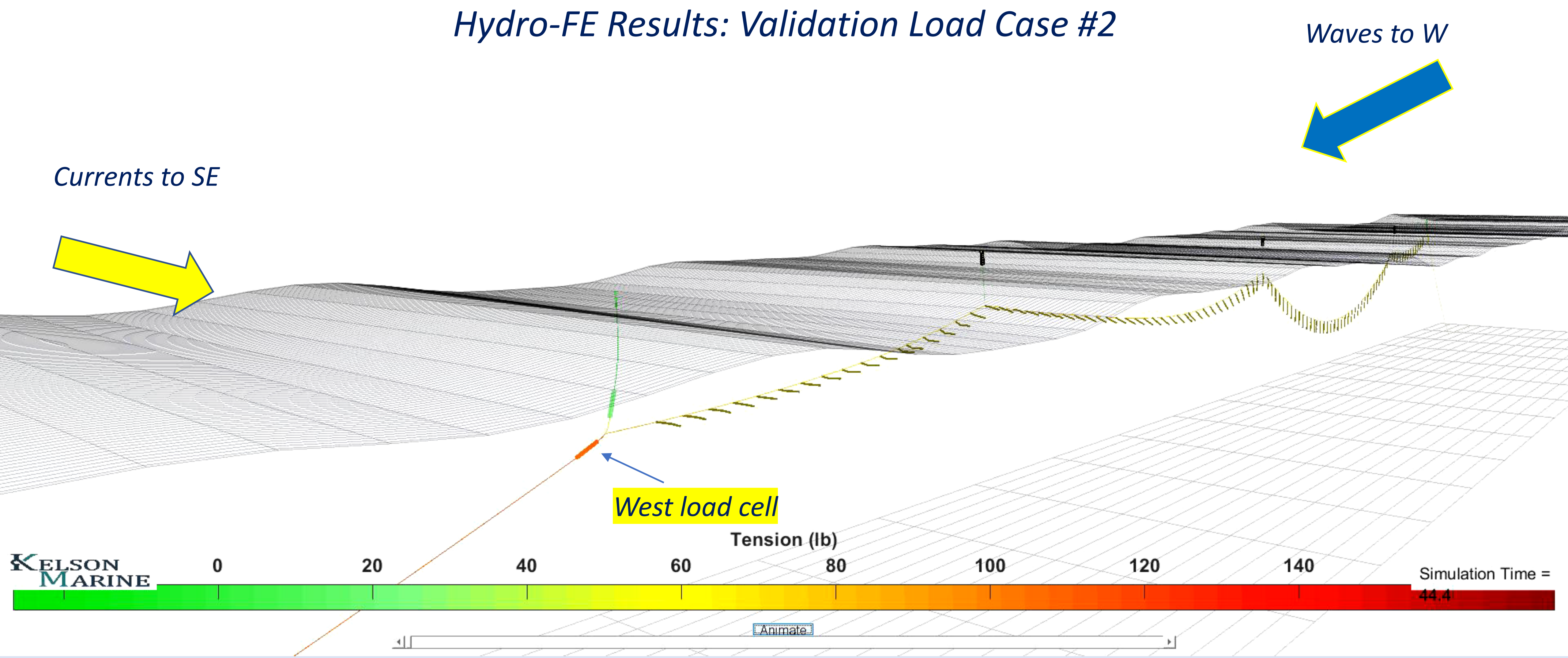
Young's modulus: 301 MPa
Second area moment: 8.54 (10^{-12}) m^4
Poisson ratio: 0.4

$$u\frac{\partial u}{\partial x} = \frac{f_{D_X}}{A_X \rho_w} \longrightarrow U_n = U_{n-1} - \left(\frac{f_{D_X}}{A_X \rho_w U_n}\right)(x_{n-1} - x_n)$$

March down each aggregate

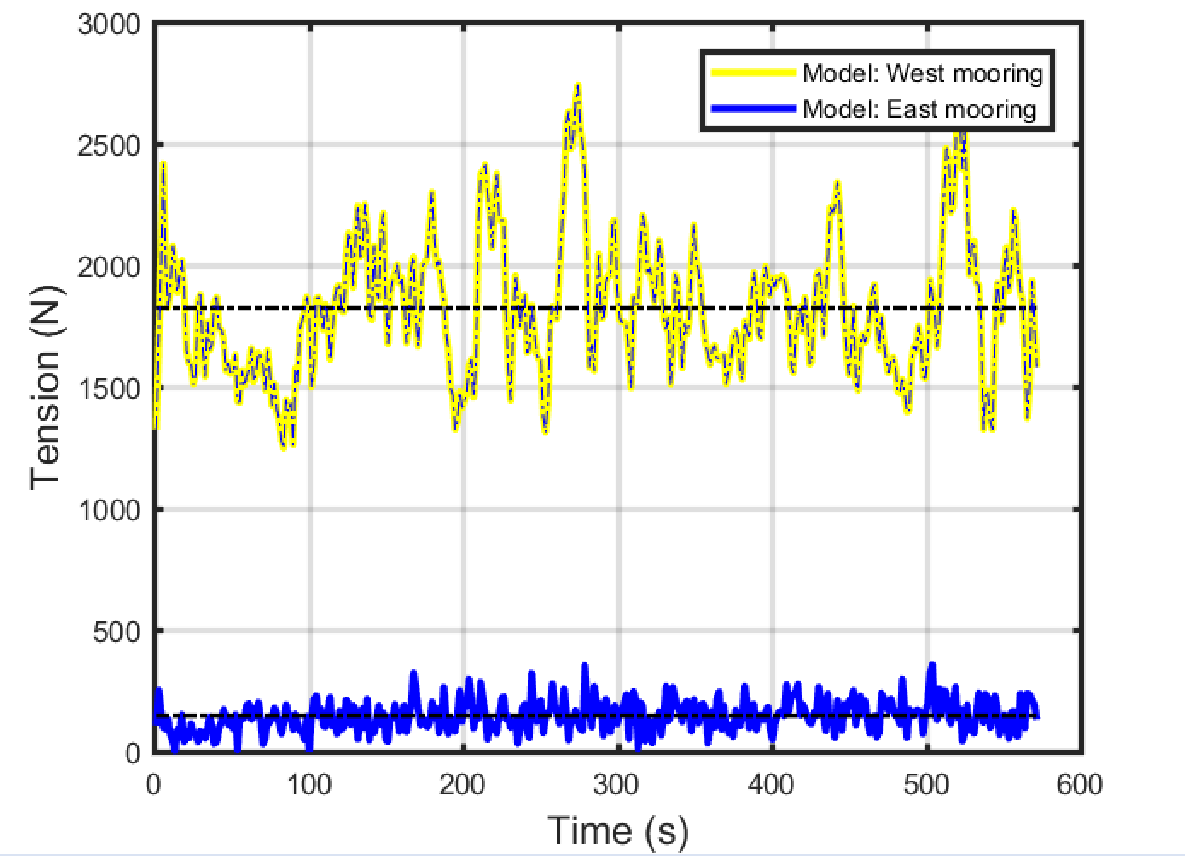


Results: Model Validation with Field data (122-m)

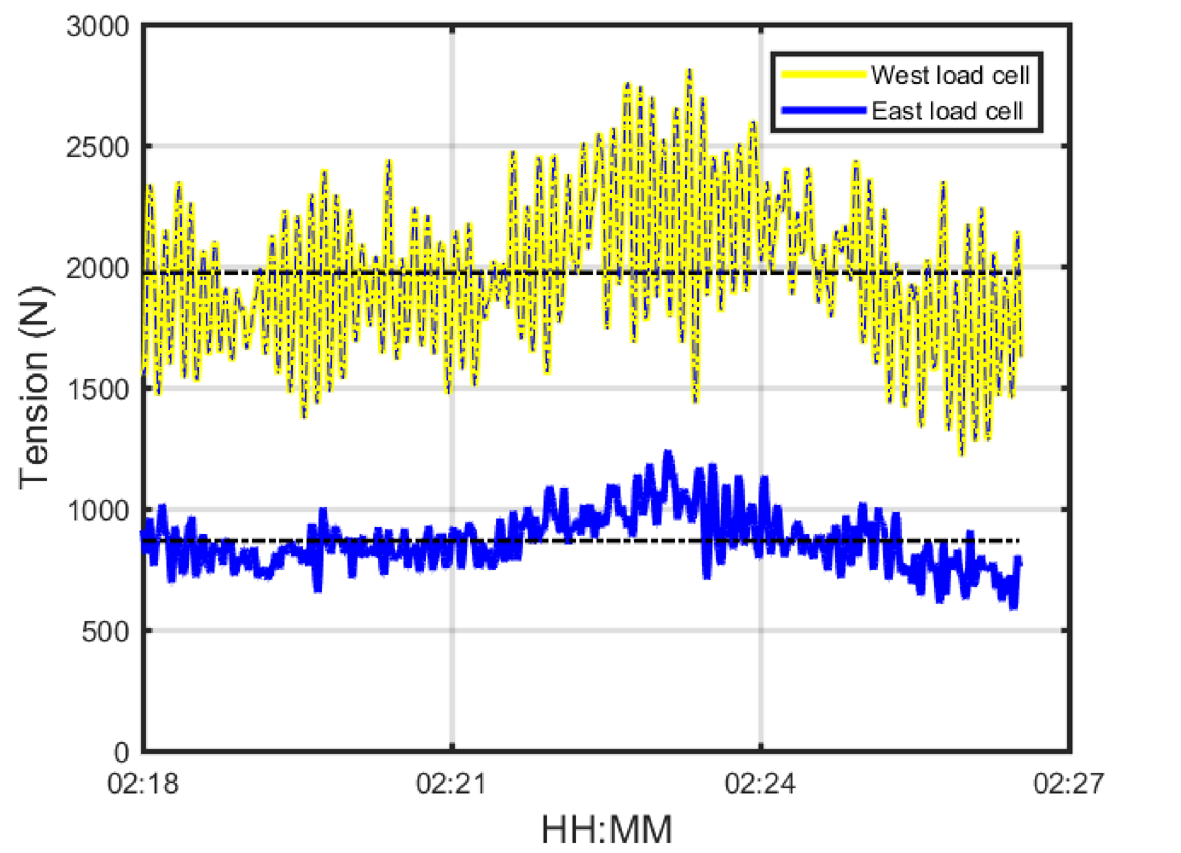


Results: Model validation with field data (load case #2)

Hydro-FE Results



Field Data Results



<u>Model: West Mooring</u>
Mean = 1824 N
Maximum = 2849 N
Minimum = 1246 N
Stand Dev = 283 N

<u>Load Cell: West Mooring</u>
Mean = 1974 N
Maximum = 2816 N
Minimum= 1216 N
Stand Dev = 299 N

% Difference of max using $Mean + 2\sqrt{var}$ = **7.0%**

Results: Model validation with field data (5 load cases)

		Currents		Waves			
Load Case	Date/Time	Speed (m/s)	Direction (deg)	H_s (m)	Dir (deg)	Tide (m)	**% Difference** $\boldsymbol{Mean + 2\sqrt{var}}$
1	26-Apr-2019 22:15	0.26	250	1.3	97	16.5	**-31%**
2	27-Apr-2019 02:15	0.29	277	1.7	91	14.9	**-6%**
3	27-Apr-2019 10:15	0.19	242	1.8	92	16.7	**-6%**
4	27-Apr-2019 15:15	0.23	254	1.3	86	14.6	**6%**
5	27-Apr-2019 18:15	0.20	268	1.0	89	14.8	**2%**

Fredriksson, D.W., Dewhurst, T., St. Gelais, A.T., Johndrow, K., Drach, A., and Costa-Pierce (2021). High fidelity approach using empirical and field datasets to validate a kelp aquaculture system numerical model. Ocean Eng. In prep.).

1. Compare west load cell with model results: **≈ 15%**
2. Finalizing manuscript – checking numbers
3. Use empirical/field data validation approach as a basis for standards